Application Note

MCF8316A - Design Challenges and Solution

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ABSTRACT

The MCF8316A provides a single-chip, code-free sensorless FOC solution for customers driving BLDC motors for applications such as residential fans, ceiling fans, air purifiers, washer pumps, and so forth. With more than 50 parameters to tune, it can feel overwhelming and time consuming for customers to tune their motor and meet all system requirements. This application note provides an in-depth discussion of three of the most common design challenges with the MCF8316A and step-by-step guidance on how to address these challenges.

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1 Introduction

Some of the common challenges in tuning a Sensorless Field Oriented Control-based Motor driver are minimizing motor startup time, improving motor speed stability, and system efficiency. Motor startup time is very critical in applications such as Medical CPAP blowers. With the MCF8316A, system designers can minimize the motor start-up time by configuring the motor start-up parameters. Motor speed stability is critical in applications such as washer and dishwasher pumps, residential fans, and so forth. The integrated speed control loop in the MCF8316A helps maintain a constant speed over varying load conditions. For integrated control motor drivers, temperature is often a critical design specification that cannot be violated. With the MCF8316A, system designers can minimize power losses by configuring PWM output frequency, slew rate and PWM modulation scheme.

2 Design Challenges and Solutions

2.1 Minimizing Motor Startup Time

In this application note, startup time is defined as the time taken for the motor to enter closed loop from a stationary position. The MCF8316A provides four different motor startup methods as listed below:

- Align
- Double align
- Initial Position detect (IPD)
- Slow first cycle

Double align is not discussed in this application note as this method takes the maximum time to start up the motor.

2.1.1 Align

The MCF8316A aligns the motor by injecting a DC current through a particular phase pattern for a certain duration of time. Below are the dominant parameters that impact startup time during align and open loop operation.

- Align time [ALIGN_TIME]
- Align or slow first cycle current limit [ALIGN_OR_SLOW_CURRENT_LIMIT]
- Starting frequency of first cycle [FIRST_CYCLE_FREQ_SEL]
- Open loop acceleration coefficient A1 [OL_ACC_A1]
- Open loop acceleration coefficient A2 [OL_ACC_A2]
- Auto handoff from open to closed loop [AUTO_HANDOFF_EN]
- Minimum BEMF for auto handoff [AUTO_HANDOFF_MIN_BEMF]

Figure 2-1 shows the Q-axis current i_{qref} and motor electrical frequency f_{ele} with respect to time. During align, the motor driver ramps up the phase current from zero to the configured ALIGN_OR_SLOW_CURRENT_LIMIT. Current ramps at the rate configured by ALIGN_SLOW_RAMP_RATE for the duration configured by ALIGN_TIME.

After the align time, the MCF8316A begins to accelerate the motor in open loop with the first cycle open loop frequency configured by FIRST_CYCLE_FREQ_SEL and ramps up the motor speed to the handoff frequency f_{ele}.

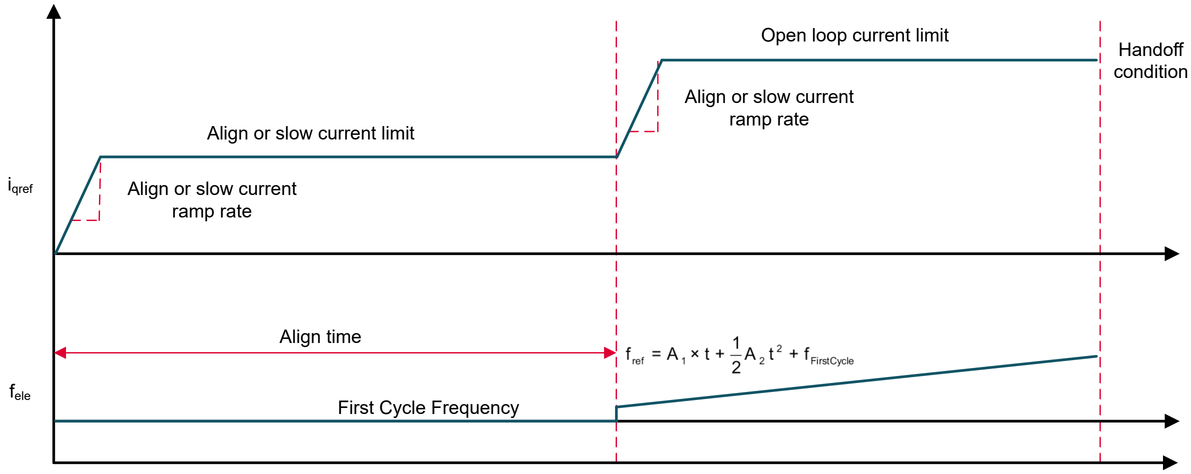

Figure 2-1. Q-Axis Current and Motor Electrical Frequency During Align

To minimize the motor startup time during align operation, it is recommended to decrease the align time [ALIGN_TIME] and increase the align or slow first cycle current limit [ALIGN_OR_SLOW_CURRENT_LIMIT] to a value closer to the rated current of the motor.

Note

Decreasing the align time to a very low value might not provide sufficient time for the rotor to settle down to a known position. Also, increasing the align or slow first cycle current limit to a very high value might cause the rotor to oscillate or vibrate due to excessive torque.

To minimize the motor startup time in open loop operation, it is recommended to increase the Starting frequency of first cycle [FIRST_CYCLE_FREQ_SEL], open loop acceleration coefficient A1 [OL_ACC_A1] and A2 [OL_ACC_A2], enable auto handoff [AUTO_HANDOFF_EN] and set the minimum BEMF for auto handoff [AUTO_HANDOFF_MIN_BEMF] to 0 mV.

Note

Setting very high acceleration coefficients A1 and A2 can cause the motor to lose synchronization and result in a motor startup failure.

Figure 2-2 shows the FG and phase current of a BLDC motor. FG is configured to output pulses in closed loop. This is to know exactly at what point the motor enters closed loop. Bottom half of the figure shows the phase current that is zoomed to show the align current. The align current should be a DC current without any oscillations. Figure 2-3 shows the time taken for the BLDC motor to enter closed loop which is 363 ms.

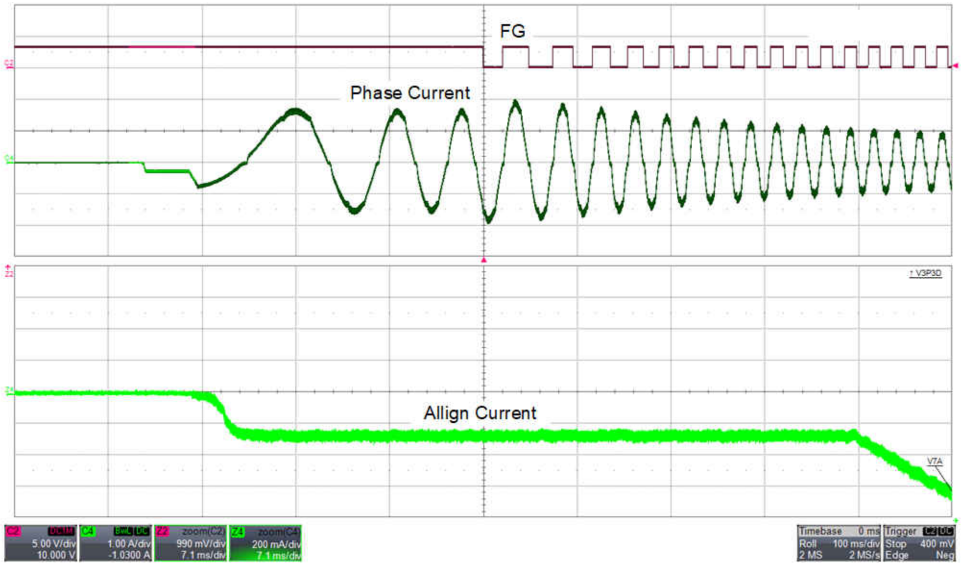

Figure 2-2. Phase Current and FG During Align

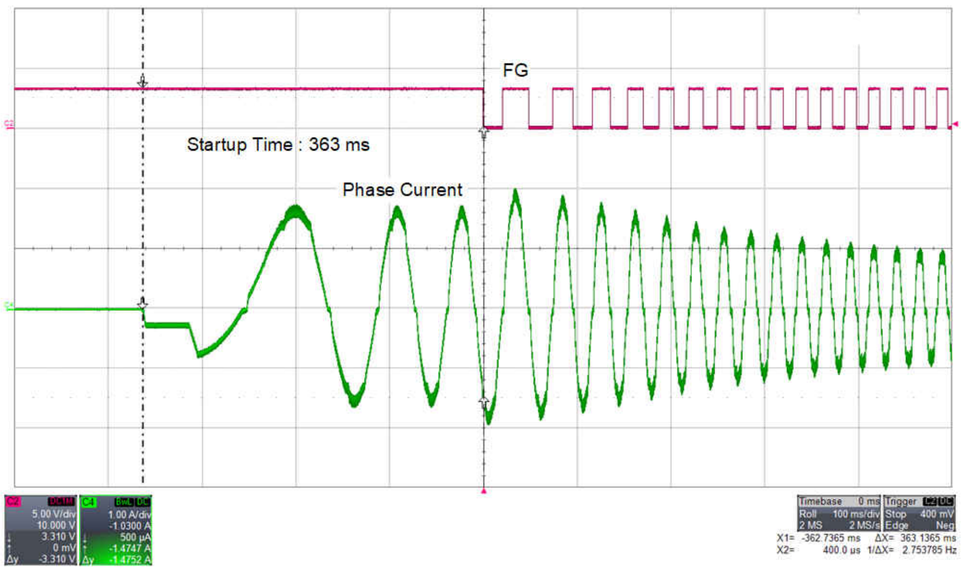

Figure 2-3. Time Taken to Enter Closed Loop in Align

2.1.2 Initial Position Detect (IPD)

Initial Position Detection (IPD) method determines the initial position of the motor using the spatial variation in the motor inductance. IPD operates by sequentially applying six different phase voltage patterns. When the current through a particular phase pattern reaches the programmed threshold, the MCF8316A stops driving the particular phase pattern and measures the time taken from the start of the voltage that was applied to that particular phase pattern to the time that the current through the phase pattern reached the current threshold. This time varies as a function of the inductance in the motor windings. The state with the shortest time represents the state with the minimum inductance. The minimum inductance is because of the alignment of the north pole of the motor with this particular driving state.

Below are the dominant parameters that impact startup time during IPD. Open loop parameters are discussed in Section 2.1.1.

- IPD current threshold [IPD_CURR_THR]
- IPD release mode [IPD_RLS_MODE]
- IPD Clock frequency [IPD_CLK_FREQ]
- IPD repeating times [IPD_REPEAT]

Figure 2-4 shows the IPD current pulses along with the above four parameters labeled in the plot.

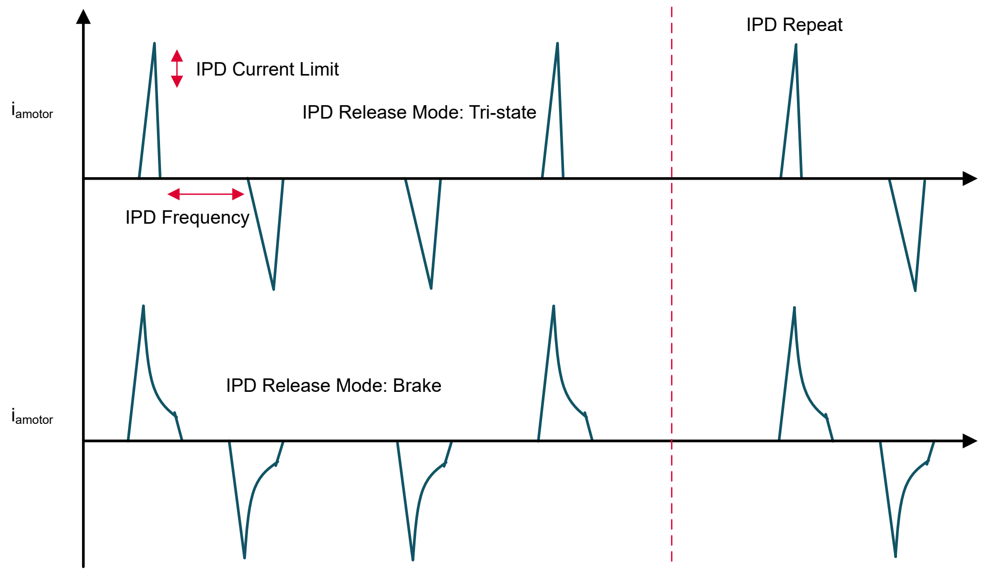

Figure 2-4. IPD Current Pulses in Tri-State and Brake Mode

Follow the below steps to minimize the motor startup time during IPD operation.

1. Configure the IPD current threshold [IPD_CURR_THR] to a value closer to the rated current of the motor.

> **Note**
> If the motor vibrates or spins in reverse direction, it is recommended to decrease the IPD current threshold.

2. Configure IPD release mode [IPD_RLS_MODE] to Tri-state or Hi-Z as the phase current has a faster settle-down time.

> **Note**
> Setting the IPD release mode to Tri-state can result in a voltage increase on VM. The user must manage this with an appropriate selection of either a clamp circuit or by providing sufficient capacitance between VM and GND to absorb the energy.

3. Increase the IPD Clock frequency [IPD_CLK_FREQ] until there is no overlapping between consecutive IPD current pulses as shown in Figure 2-6. IPD current should settle down completely before starting of the next pulse. Figure 2-6 shows an example of IPD current pulses with ideal time difference between the pulses. Figure 2-5 shows an example of an unsettled IPD current pulse where the consecutive current pulses overlap.

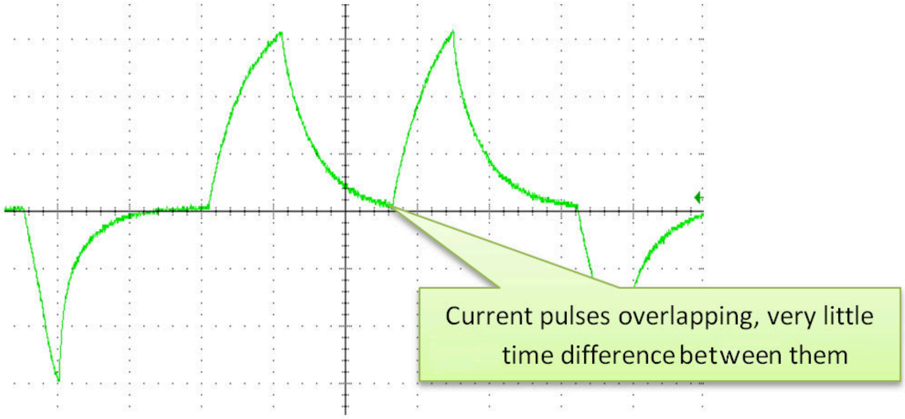

Figure 2-5. Overlapping IPD Current Pulses

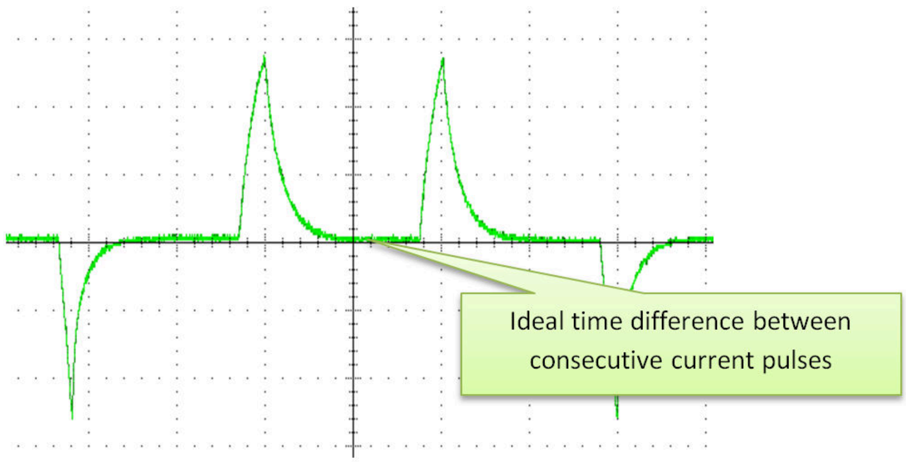

Figure 2-6. IPD Current Pulses Showing Ideal IPD Clock Frequency

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Note

Motor with high inductance and high current thresholds require longer time for the current to settle down. For such motors, it is recommended to set a lower IPD frequency. Setting a lower IPD frequency makes IPD noise louder and increases the motor startup time.

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4. Configure IPD repeating times [IPD_REPEAT] to 1.

   Figure 2-7 shows the FG and phase current of a BLDC motor. FG is configured to output pulses in closed loop. This is to know exactly at what point the motor enters closed loop. The bottom half of the figure shows the phase current that is zoomed to show the IPD current pulses. Figure 2-8 shows the time taken for the BLDC motor to enter closed loop which is 219 ms.

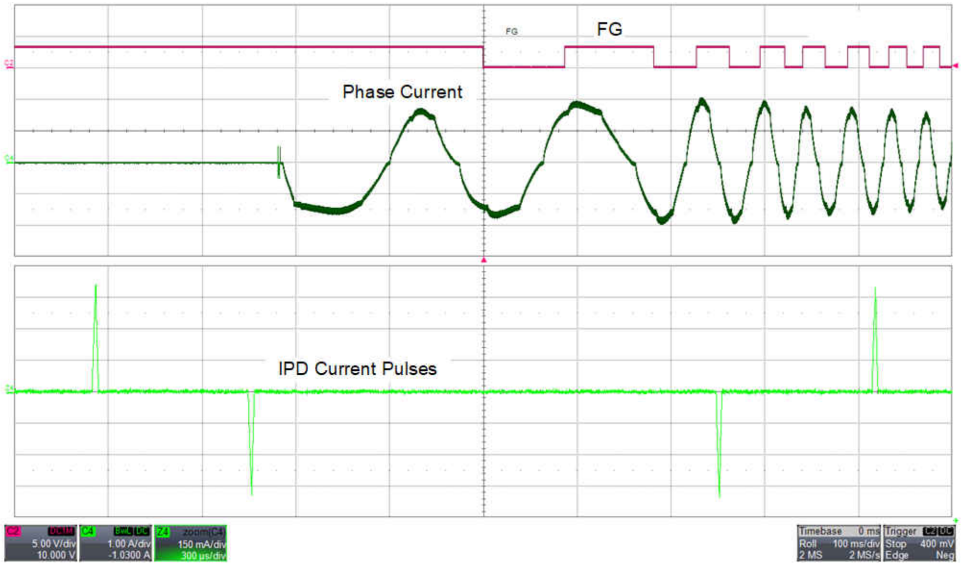

Figure 2-7. Phase Current and FG During IPD

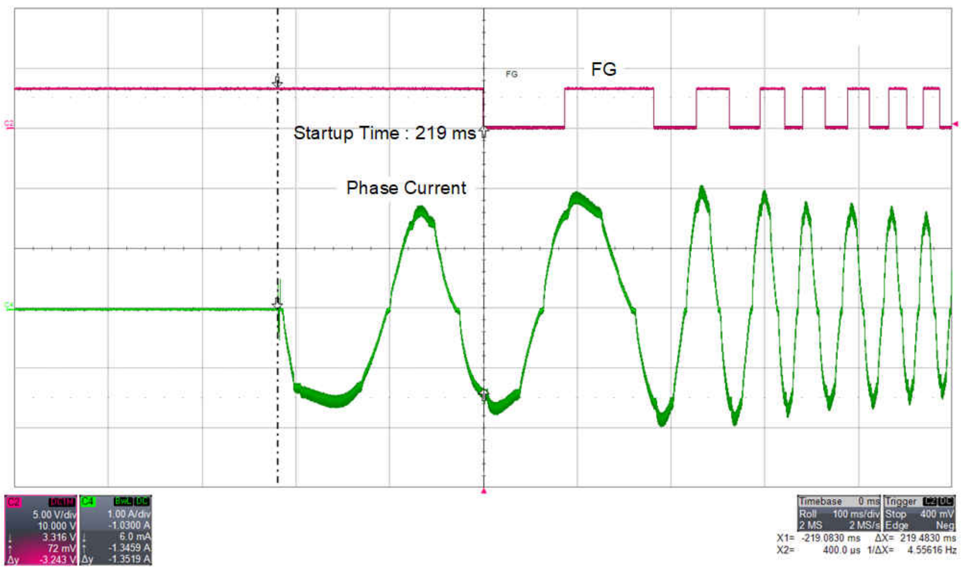

Figure 2-8. Time Taken to Enter Closed Loop in IPD

2.1.3 Slow First Cycle

In slow first cycle start-up method, MCF8316A starts motor commutation at a frequency defined by SLOW_FIRST_CYCLE_FREQ. The frequency configured is used only for first cycle, and then the motor commutation follows acceleration profile configured by open loop acceleration coefficients A1 and A2. The slow first cycle frequency has to be configured to be slow enough to allow motor to synchronize with the commutation sequence.

Below are the dominant parameters that impact startup time during slow first cycle. Open loop parameters are discussed in Section 2.1.1.

- Frequency of first cycle [SLOW_FIRST_CYC_FREQ]
- Align or slow first cycle current limit [ALIGN_OR_SLOW_CURRENT_LIMIT]

Figure 2-9 shows the Q-axis current i_{qref} and motor electrical frequency f_{ele} with respect to time.

During Slow first cycle, MCF8316A begins to accelerate the motor in open loop with the first cycle open loop frequency configured by FIRST_CYCLE_FREQ_SEL and ramps up the motor speed to the handoff frequency f_{ele}.

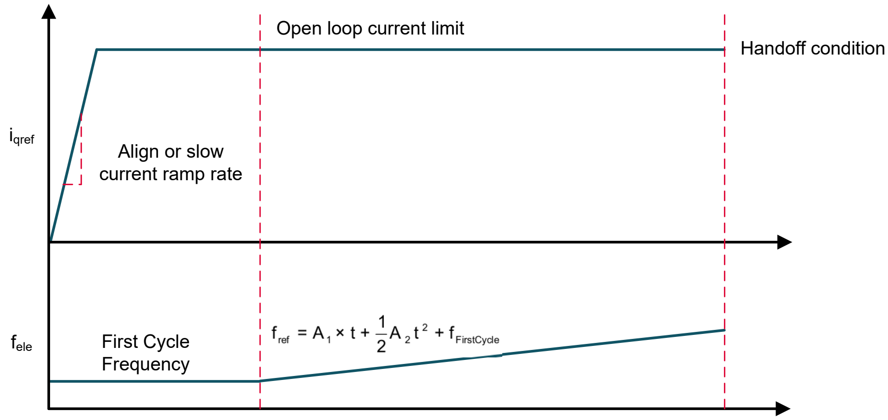

Figure 2-9. Q-Axis Current and Motor Electrical Frequency During Slow First cycle

To minimize the motor startup time during slow first cycle operation, it is recommended to increase the frequency of first cycle [SLOW_FIRST_CYC_FREQ] and increase the align or slow first cycle current limit [ALIGN_OR_SLOW_CURRENT_LIMIT] to a value closer to the rated current of the motor.

Note

Setting the frequency of first cycle to a very high value might cause the motor to lose synchronization. It is recommended to start with a lower value and slowly increase the frequency to ensure the motor spins smoothly. Increasing the align or slow first cycle current limit to a very high value might cause the rotor to oscillate or vibrate due to excessive torque.

Figure 2-10 shows the FG and phase current of a BLDC motor. FG is configured to output pulses in closed loop. This is to know exactly at what point the motor enters closed loop. Time taken for the BLDC motor to enter closed loop is 120 ms.

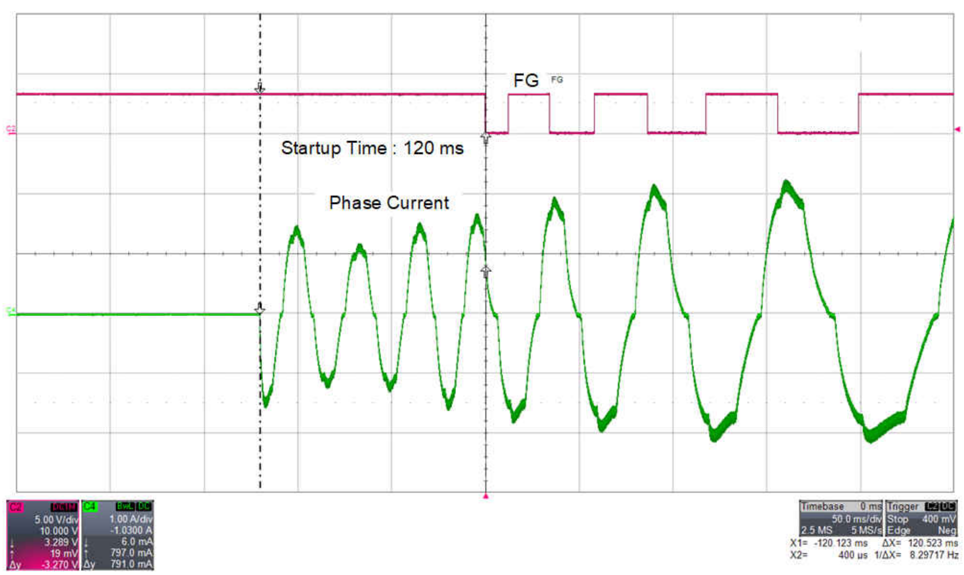

Figure 2-10. Time Taken to Enter Closed Loop in Slow First Cycle

2.2 Improving Motor Speed Stability – Tuning Speed PI Controller

The integrated speed control loop in MCF8316A helps maintain a constant speed over varying operating conditions. The Kp and Ki coefficients of the Speed PI controller are configured through SPD_LOOP_KP and SPD_LOOP_KI. These coefficients are tuned either manually or automatically to achieve better speed stability and speed regulation.

2.2.1 Auto Tuning

MCF8316A auto tunes Kp and Ki coefficients after measuring the mechanical parameters such as friction coefficient, moment of inertia through MPET.

Follow the below steps to auto tune Kp and Ki coefficients:

1. Program SPD_LOOP_KP and SPD_LOOP_KI to zero.
2. Enable MPET Ke measurement by setting MPET_KE to 1.
3. Run the MPET by setting MPET_CMD to 1. Motor starts to spin.
4. After motor stops spinning, SPD_LOOP_KP and SPD_LOOP_KI gets updated to auto tuned Kp and Ki values.
5. Issue run command and track the motor speed.
6. If there is any overshoot during ramp up, check the closed loop current and set the open loop current same as closed loop current.

Figure 2-11 shows the FG, phase current and motor electrical speed in Hz with auto tuned Kp and Ki. Motor speed steadily ramps up to the target speed without any overshoots.

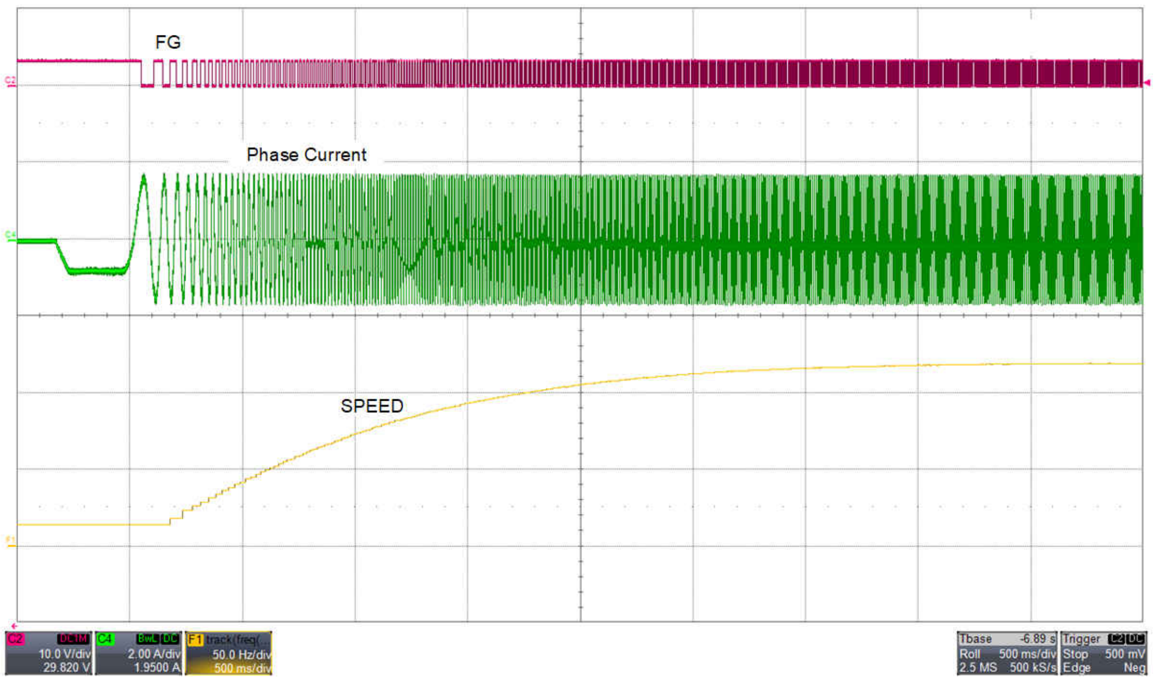

Figure 2-11. FG, Phase Current and Motor Electrical Speed in Hz With Auto Tuned Kp and Ki

2.2.2 Manual Tuning

Kp and Ki coefficients can also be tuned manually by following below steps:

1. Disable Speed loop by setting SPEED_LOOP_DIS to 1.
2. Disable closed loop by setting CLOSED_LOOP_DIS to 1.
3. Spin the motor in open loop by issuing non-zero speed command.
4. Allow the open loop current to settle down and then measure the peak open loop phase current. Check the sign of the phase current by reading the Estimated Iq (register address: 0x000004E6).
5. Enter 110% of measured peak phase current as the Iq reference in FORCE_IQ_REF_SPEED_LOOP_DIS. To convert Iq reference to FORCE_IQ_REF_SPEED_LOOP_DIS, see the *MCF8316A Sensorless Field Oriented Control (FOC) Integrated FET BLDC Driver Data Sheet*.
6. Enable closed loop by setting CLOSED_LOOP_DIS to 0.
7. Adjust the FORCE_IQ_REF_SPEED_LOOP_DIS such that the motor speed reaches the maximum speed.
8. Calculate Speed loop Kp [SPD_LOOP_KP] and Speed loop Ki [SPD_LOOP_KI] using equation 1 and 2.
9. Enable speed loop by setting SPEED_LOOP_DIS to 0.

$$Speed\ loop\ Kp = \frac{Iq\ reference\ at\ maximum\ speed}{Maximum\ Electrical\ Speed\ in\ Hz}$$

$$Speed\ loop\ Ki = 0.1 \times Speed\ loop\ Kp$$

Figure 2-12 shows the FG, phase current and motor electrical speed in Hz with manually tuned Kp and Ki. Motor speed steadily ramps up to the target speed without any overshoots.

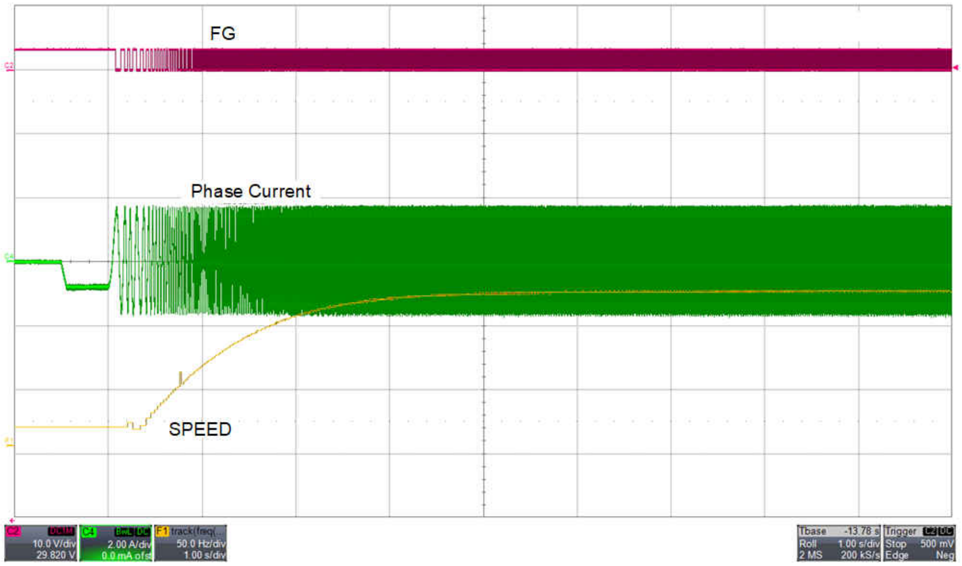

Figure 2-12. FG, Phase Current and Motor Electrical Speed in Hz With Manually Tuned Kp and Ki

Figure 2-13 shows FG, phase current and motor electrical speed in Hz when the phase current drops from 3A to 1.5A. With well-tuned speed controller Kp and Ki coefficients, speed slightly overshoots for less than a second and recovers back to the steady state speed.

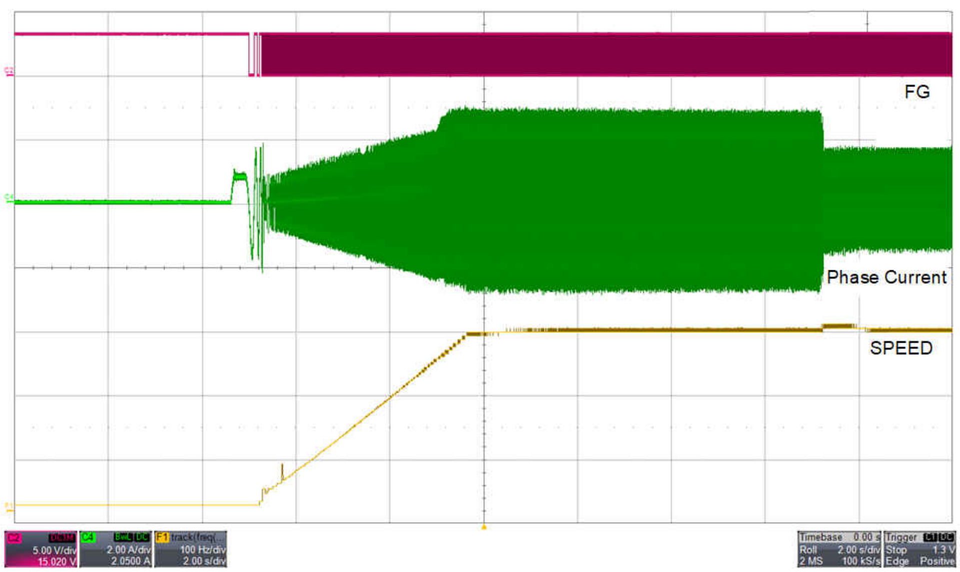

Figure 2-13. FG, Phase Current and Motor Electrical Speed in Hz When the Phase Current Drops From 3A to 1.5A

2.3 Improving System Efficiency by Minimizing Power Losses

Power dissipation in MCF8316A can be from various sources such as R_{dsOn} of the MOSFETs, MOSFET switching losses, MOSFET slew rate, operating supply current dissipation, and so forth. MCF8316A provides configurable options to minimize power losses and maximize thermal efficiency.

Power losses in MCF8316A can be minimized by enabling buck regulator power sequencing [BUCK_PS_DIS], increasing the slew rate [SLEW_RATE], decreasing the PWM output frequency [PWM_FREQ_OUT] and configuring the PWM modulation scheme to “Discontinuous space vector PWM modulation”.

Figure 2-14 shows the thermal image of MCF8316A at Continuous PWM modulation, slew rate at 50 V/µs, 50 kHz and buck regulator power sequencing disabled. With these configurations, device case temperature is 109.8˚C on a four-layer, 1 oz copper thickness PCB.

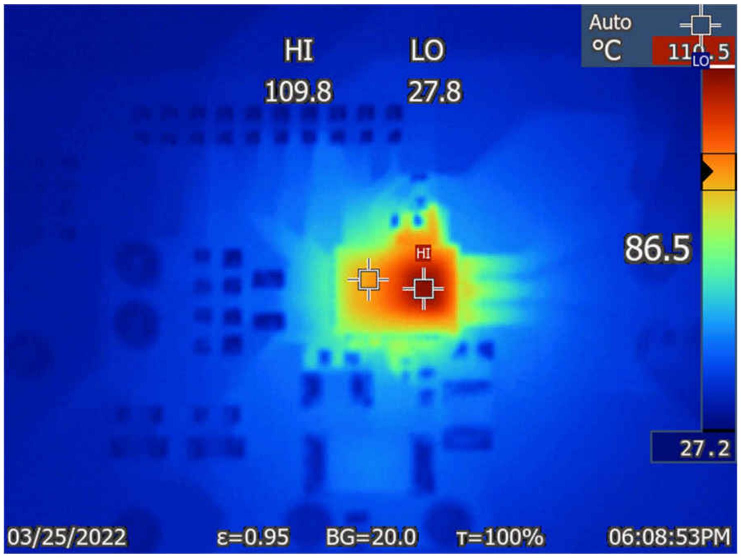

Figure 2-14. Thermal Image of MCF8316A – Higher Case Temperature

Figure 2-15 shows the thermal image of MCF8316A at discontinuous PWM modulation, slew rate at 200 V/µs, 20 kHz and buck regulator power sequencing enabled. With these configurations, device case temperature dropped to 75.4˚C on a four-layer, 1 oz copper thickness PCB.

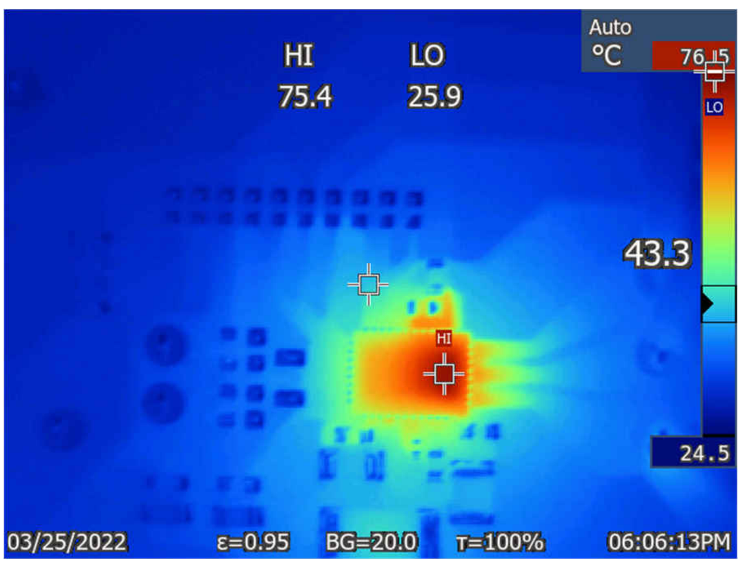

Figure 2-15. Thermal Image of MCF8316A - Lower Case Temperature

3 References

- Texas Instruments, *MCF8316A Sensorless Field Oriented Control (FOC) Integrated FET BLDC Driver Data Sheet*
- Texas Instruments, *MCF8316A Tuning Guide*
- Texas Instruments, *How to Design a Thermally-Efficient Integrated BLDC Motor Drive PCB*
- Texas Instruments, *Thermal Calculator*